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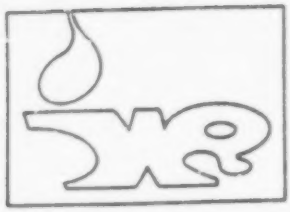

Program Report 86–8
July 1986

Interaction of Knowledge, Learning, and Development

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ABSTRACT

The purpose of this paper is to review the relevant evidence concerning the relationship between knowledge and its effect on learning, with an end to answering the questions: (1) How important is knowledge to learning? and (2) How does the relative importance of knowledge change with development? The paper is divided into three main sections: evidence for domain-specific learning, evidence for domain-independent learning, and implications for developmental theory. The domain-specific section uses evidence from three areas of research to show that previously acquired knowledge affects the learning of subsequent, related information. In the section on domain-independent learning, it is argued that at least some aspects of learning may be relatively domain independent. This argument is supported by demonstrating that training children to use metacognitive skills allows the transfer of these skills from one domain to another. In the last section, three prominent developmental theories (learning theory, Piagetian theory, and the "capacity" theory of information processing) are examined. A knowledge-based theory is presented to explain development in terms of the amount of factual and strategic knowledge that an individual has acquired. The theory argues that it is the unequal distribution of this knowledge that accounts for the apparent differences in children's and adult's reasoning processes. An eight-page reference list concludes the document. (JAZ)

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Program Report 86-8

INTERACTION OF KNOWLEDGE, LEARNING, AND DEVELOPMENT

Karen L. Rembold and Steven R. Yussen

Report from the Project on Metacognitive Aspects of Prose Comprehension

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July 1986

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Wisconsin Center for Education Research

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. . . if there is one dichotomy that permeated this conference, it [is] the basic nature of problem solving. Specifically the poles are Domain-Independence of Problem-Solving versus Domain-Specificity of Problem-Solving. The dichotomy is an old one.

Allen Newell, 1979, Carnegie Mellon Conference on Problem Solving and Education

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Introduction

Although the number of studies concerning children's knowledge about natural concepts (e.g., time, space, etc.) has dramatically increased in the past two decades, the number of studies concerning children's learning has considerably decreased (Stevenson, in press). One of the factors to which Siegler (1983) has attributed this lack of studies on learning is an "incompatibility between the basic assumption that learning mechanisms operate in the same way regardless of context and the mounting realization that people's learning and remembering are crucially affected by what they already know" (p. 263). Perhaps the most dramatic demonstration of this interaction between learning and knowledge is Chi's (1978) finding that child "experts" in a particular domain (chess, in this case) are capable of remembering more than adults who are naive in the domain. The reading comprehension literature, as well, is replete with studies (e.g., Brown, Smiley, Day, Townsend, & Lawton, 1977; Dooling & Lachman, 1971) showing that knowledge of a particular topic area increases memory and comprehension in that area.

The purpose of the present paper is to review the relevant evidence concerning the effects of knowledge on learning, with an end to answering the following questions: (1) Exactly how important is knowledge to learning; for example, are there situations in which knowledge does not appear to play a role in learning at all? and (2) How does the relative importance of knowledge change with development? To answer these questions, the paper is divided into three main sections: evidence for domain-specific learning, evidence for domain-independent learning, and implications for developmental theory. In a concluding section, we examine unanswered questions and suggest future directions for research. The research to be reviewed is drawn primarily from the fields of reading comprehension and cognitive psychology and, when available, focuses on the school-aged child. Studies of adults are included to provide examples of mature learners.

Before examining the research, however, it is necessary to include some working definitions of the terms knowledge and learning. Knowledge is probably most simply defined as information, understanding, or recognition (Webster's New Twentieth Century Dictionary, 1978) and can be broken down into the categories of information about facts, or "static" knowledge, and information about procedures, or "strategic" knowledge (Brown, Bransford, Ferrara, & Campione, in press).

One of the most difficult problems facing psychologists is determining whether, and to what extent, knowledge has been acquired, or learned. Obviously there are multiple criteria that can be used to make this judgment. One can assume that just exposing individuals to a piece of information will in some way change their relationship to that information, even if the change is minute and they are unaware of it. Alternatively, one can depend on individuals' self-reports concerning whether or not they possess information in a particular area. Or one can be more rigorous and insist on some independent form of confirmation that learning has occurred. In the case of factual knowledge, one can require that information be recognized or recalled, or that it have some other demonstrable effect on an individual's

production. And in the case of procedural knowledge, one can require that the use of a strategy will improve performance on the task for which it is taught.

Even when these more rigorous criteria are used, however, decisions about definition still arise. If a second grader "learns" a nursery rhyme but cannot recall it two years later, are we to assume that he never really learned the material? Or if a child can use a strategy, for example rehearsal, on a familiar but not an unfamiliar type of task (see Gelman, 1978), must we decide that she actually doesn't know how to apply the procedure?

Clearly, some sorts of arbitrary decisions must be made. For the purposes of this paper, factual knowledge will be said to be learned if it can be recalled or recognized immediately after presentation. Information that is not produced at delayed intervals will be viewed as forgotten. And information that is not forgotten will be assumed to have been better learned than information that is forgotten. In the case of procedural knowledge, a strategy will be said to be learned if it can be used successfully in the situation in which it was learned. Strategies that can be spontaneously generalized to one or more applicable situations will be said to be better learned that those that cannot be generalized.

Evidence for Domain-Specific Learning

Research on Prior Knowledge

One way to provide support for the argument that the effectiveness of learning mechanisms is dependent on the subject matter being learned is to demonstrate that knowledge about a particular subject domain effects the learning of new information in that domain. Quite a few studies have been conducted that make this point in one way or another, and the following discussion is designed to summarize the evidence that has been amassed.

One of the earliest researchers to acknowledge the importance of prior experience or knowledge in learning was Bartlett (1932). Bartlett found that adults' recall of stories conspicuously failed to replicate the texts that they had actually heard. Instead, their recall protocols were characterized by the omission of details, the intrusion of new facts, the transformation of temporal occurrences, and the integration of several points of information into one.

Since Bartlett's time, many researchers have conducted prose comprehension studies with adults and shown that even a slight amount of prior information about a prose passage can affect various dependent measures of the learning of that passage (Tripathi & Tripathi, 1981). For example, Dooling and Lachman (1971) demonstrated that the presentation of a title before a metaphorical passage facilitates free recall of the passage, as well as recognition of thematically relevant words from the passage. Yoshida (1979) demonstrated that the provision of either a main theme or a main theme plus paragraph subthemes, prior to reading a passage, increases performance on both fact and inference tests concerning the passage. Gardner and Schumacher (1977) showed that prior presentation of a theme-relevant prepassage increases both free recall and cued recall of the target passage. And, in a somewhat more ecologically valid study, Nolan, Haggmeyer, and Vig (1978) showed that having lived through an era slightly aids recall of an historical passage about the events of that era.

Studies confirming these basic results have also been conducted with children and adolescents. Among high school students, Hartley, Kenely, Owen, and Truemen (1980) showed that statement or question headings in a passage facilitate both immediate and delayed (two weeks) free recall of the passage. And in a study of second through seventh graders, Brown, Smiley, Day, Townsend, and Lawton (1977) found that the provision of an appropriate theme prior to an ambiguous passage increases free recall of the passage. Brown et al. were struck by the absence of developmental differences among their variably aged subjects and by the similarity of children's responses and reports of adult findings. They concluded that children respond like adults in the recognition and recall of prose passages when prior knowledge is either provided or withheld.

Even more convincing than the mere demonstration that some knowledge about a passage can facilitate its learnability are studies which demonstrate that the amount of prior knowledge about a topic

predicts recall of passages concerning that topic. Mills and Nicolas (1966) had adults rate their degree of familiarity to various topics expressed in sentences; they found a positive correlation between recall of the sentences from a prose passage and their rated degree of familiarity. Langer and Nicolich (1981) measured high school students familiarity with key concepts and terms in a passage by counting the number of appropriate words that students could freely associate with them. When students subsequently read the target passage, Langer and Nicolich found a strong relationship between students' prior level of familiarity with the information and their recall of it. In addition to these studies that show the effects of level of prior knowledge, other research has shown effects on recall due to whether prior information is provided in a verbal or pictorial form (Bernard, Peterson, & Ally, 1981; Borges & Robins, 1980; Sherman, 1976), whether in a concrete or an abstract form (Royer & Cable, 1975), whether students are provided with prior information or generate their own (Christie & Schumacher, 1976), whether students tend to be more or less stimulus bound (Spiro & Tirre, 1980), and how prior knowledge interacts with text structure (Mathews, 1981).

Having seen that providing subjects with even a modest amount of information can aid in their acquisition of future information, it is important to consider <u>why</u> these results occur so consistently. In his attempts to account for what he had observed, Bartlett (1932) argued that people had certain expectations about what would occur in any given story and that their expectations had developed from past experience. Incoming information that did not correspond to these expectations would be distorted in some way. Bartlett referred to these expectations-developing-from-past-experiences as "schemata," and his speculations have, in part, formed the basis for present-day schema theory.

Schemata (or schemas) are defined as highly organized structures which store the conceptualizations of persons, objects, events, and actions, as well as sequences of these phenomena (Minsky, 1975; Rumelhart, 1980; Rumelhart & Ortony, 1977; Schank & Abelson, 1977). They are assumed to be formed by observing multiple examples of a category, such that an abstract or generic form of the category comes into existence (Stein & Trabasso, 1981).

Schemata are important for the field of psychology in general because they are believed to simplify the storage of concepts as well as to guide the acquisition of new information, as Bartlett hypothesized. They are specifically important to the present discussion for two reasons. First of all, they emphasize the importance of past experience, or knowledge, in the <u>formation</u> of even quite abstract structures, since schemata are believed to result from multiple exposures to specific instances of a category. Secondly, they are a necessary ingredient for the argument that learning mechanisms are context-dependent, because they provide a reason for <u>why</u> prior knowledge is important, which is that this knowledge allows a particular schema to be instantiated, or called up from memory, and hence allows related material to be learned.

There are several different strands of research that provide support for the notion that the mechanism underlying the facilitating effects of prior knowledge is schema instantion. One of these strands makes overt what all of the previously cited studies have merely implied: information that provides an appropriate context for a target passage (i.e., is related to it) improves recall and learning more than information that does not provide such an appropriate context, whether the subjects are adults (Hertel, Cosden, & Johnson, 1980; Townsend, 1980) or school-aged children (Aulls, 1975; Yussen & Mazor, 1983). This assumption is critical to schema theory because new information is believed to be learned via its connection to previously acquired, related material.

A second strand of research has to do with whether knowledge is provided prior to the encoding or to the retrieval of the target passage. Several studies with adults have shown that information that is provided prior to encoding of the target passage (i.e., before the target passage is read) facilitates recall to a significantly greater extent than material that is provided prior to retrieval of the target passage (i.e., after the target passage is read but before recall is attempted) (Bransford & Johnson, 1973; Dooling & Mullet, 1973; Schmid & Kulhavy, 1981; Townsend, 1980). These results are important because they are consistent with schema theory's presumption that knowledge is most helpful if it is in place before the target passage is introduced, since it is to act as a framework for the target passage's meaningful interpretation. Royer, Perkins, and Konold (1978) have shown, in addition, that inserting information before the passage, rather than before its recall, also increases the number of theme-related distractors that are falsely recognized by adult subjects. This demonstration of distortion in passage recall further highlights the effect of prior knowledge on the interpretation of the target passage.

All of this is not to say, however, that information that is presented after learning has occurred will not influence already learned material, because indeed in some cases it does (e.g., Anderson & Pichert, 1978; Dooling & Christiaansen, 1977; Spiro, 1980). But even in these cases, it appears that the effects of the later acquired information on the learned material are due to its interaction with previously acquired information, which further confirms the importance of prior knowledge (see Spiro, 1977, for discussion).

A third strand of research that supports schema theory as an explanation for the effects of prior knowledge on learning has to do with how consistent a given piece of knowledge is with the subjects' general world vi , regardless of whether it fulfills the criterion, discussed above, of merely being related to the target passage. Studies with adults (Anderson, Spiro, & Anderson, 1978; Baker, 1978; Morris, Stein, & Bransford, 1979; Royer, Perkins, & Konold, 1978; Sulin & Dooling, 1974) have indicated that prior information that is more consistent with the world, or more meaningful in a particular context, is more likely to facilitate the recall and learning of a target passage than less consistent or less meaningful information. For example, Anderson et al. (1978) have shown that foods that are part of most people's "restaurant schema" (e.g., red wine, roast beef) are more

likely to be recalled after hearing a story about a restaurant scene than after hearing a story about a supermarket scene in which the same foods were mentioned. Sulin and Dooling (1974) and Royer, Perkins, and Konold (1978) have found that when adults read a story about an individual and are told that it is about someone famous rather than ordinary (e.g., Adolph Hitler rather than Gerald Martin), they are more likely to falsely recognize distractor sentences that are consistent with their pre-experimental knowledge of the famous person.

Studies with children of various ages have reached similar types of conclusions. Landis (1982) has replicated the findings of Sulin and Dooling, and Royer et al., with second- and fifth-grade students. In a study of seven- and ten-year-olds, Ceci, Caves, and Howe (1981) have shown that, when children hear stories containing incongruous attributes of television characters and are asked to recall the stories three weeks later, they are more likely to remember facts that are consistent with their pre-experimental knowledge. In two studies with fifth-graders, Koblinsky and Cruse (Koblinsky & Cruse, 1981; Koblinsky, Cruse & Sugawara, 1978) have shown that children are more likely to remember stereotypic sex-role descriptions of male and female characters than nonstereotypic descriptions and are especially unlikely to recall the feminine traits attributed to male characters. And in another study of fifth graders, Owings, Peterson, Bransford, Morris, and Stein (1980) have demonstrated that stories that are consistent with children's world knowledge (e.g., "The tall boy played basketball") are recalled much better than stories that are less consistent with such knowledge (e.g., "The hungry boy took a nap").

The line of research just described is consistent with schema theory's explanation of prior knowledge effects on new knowledge because it stresses, once again, the necessity of a meaningful relationship between old and new knowledge before learning can occur. An even more convincing argument for schema theory's explanation of learning, however, is made by a fourth research thread which demonstrates the variable effects, on recall and learning, of various types of equally meaningful or consistent contexts for learning. One particularly interesting anecdotal example is provided by Lawler (1981), who observed his daughter using two different counting strategies when asked to do an arithmetic problem in the context of money or in the context of pure numbers. When asked the sum of 75 and 26, she responded, ". . . seventy, ninety, ninety-six, ninety-seven, . . ." and counted to 101. When asked the sum of 75 cents and 26 cents, however, she responded, "That's three quarters, four, and a penny, a dollar one" (p. 4). According to Lawler, his daughter did not connect these two counting techniques at the time the questions were posed, even though she arrived at the correct answer in both cases. It appears that the contexts of money and pure numbers evoked different counting schemata for her, even though the actual reasoning skills required were identical. A more formal demonstration of this same phenomenon has been provided by D'Andrade (cited in Rumelhart, 1980). D'Andrade randomly assigned adult subjects to two different conditions in which the same reasoning problem was couched in different frameworks. In one condition, subjects were asked to pretend that they were quality control experts in a factory, examine four cards with either numbers or letters on them, and make sure

that if the cards had a vowel on one side, they also had an odd number on the other side. In the second condition, subjects were asked to pretend they were managers in a Sears store, examine four sales slips, and make sure that if a sales slip was for $30 or more, it also had the department manager's signature on the back. Interestingly enough, although the problems involve the exact same reasoning process, only 15% of the condition 1 subjects responded correctly whereas 70% of the condition 2 subjects responded correctly. Here again it appears that two different contexts can bring different schemata to bear on what is essentially the same problem. But, in this case successful solution was not equally likely, as it was for Lawler's daughter.

Similar examples have cropped up in the prose comprehension literature (Anderson & Pichert, 1978; Grabe, 1979; Kozminsky, 1977; Pichert & Anderson, 1977), demonstrating that adults who are provided with different perspectives, prior to reading an identical passage, will recall different types of information from the passage. One of the most interesting examples has been provided by Pichert and Anderson (1977), who had their subjects read a description of a house from one of two points of view, that of a prospective home buyer or that of a burglar. Pichert and Anderson found that the subjects in each of the conditions remembered more information that was consistent with their particular viewpoint rather than that of the other subjects, so that a "prospective home buyer" was more likely to remember the leaky basement, whereas a "burglar" was more likely to recall the valuable paintings.

Research on Experts

Closely related (in theory, if not in practice) to the research on prior knowledge is the research pertaining to experts. The study of the effects of expertise on learning is a natural extension of the study of the effects of prior information on learning, as it involves a more ecologically valid examination of individuals who have a great deal of prior information in some particular subject domain. Although there is not as much information available on expert learning as there is on prior knowledge in general, the research that does exist is relatively well done and thought-provoking. The following discussion focuses on studies that have attempted to answer the basic questions of how expertise affects the recognition, recall, usage, and representation of domain-related information.

Chiesi, Spilich, and Voss (Chiesi, Spilich, & Voss, 1979; Spilich, Vesonder, Chiesi, & Voss, 1979) used a 40-item questionnaire to distinguish between adults with either a high ($\bar{X}$ = 38.33) or low ($\bar{X}$ = 16.63) level knowledge of baseball and then asked both groups to read descriptions of baseball plays. Chiesi et al. found that high-knowledge individuals were significantly more likely than low-knowledge individuals to correctly recognize whether or not they had previously seen a description of a play, especially if the difference between an actually seen description and a distractor involved a major change in how the play would be interpreted (e.g., having a player on third base, rather than first, when a single was hit). Chiesi et al. also found that high-knowledge individuals read significantly fewer sentences of each

description before responding correctly, thus demonstrating a need for less information than that required by low-knowledge individuals for making a correct recognition judgment.

In the area of recall, the findings of Anderson, Reynolds, Schallert, and Goetz (1976) suggest that being an expert in a particular area can influence the type of information that one recalls from prose passages. Anderson et al. provided 30 physical education undergraduates and 30 music education undergraduates with two ambiguous passages. One could be interpreted as either being about playing cards (the dominant interpretation) or playing musical instruments (the secondary interpretation); the other could be interpreted as either being about a prison break (dominant) or a wrestling match (secondary). (See the Appendix for the two passages.) From subsequent free-recall protocols and answers to multiple-choice questions, Anderson et al. found that the music students were significantly more likely than the physical education students to "recall" information from the first passage that was consistent with the musical instruments interpretation, whereas the physical education students were significantly more likely than the music students to "recall" information from the second passage that was consistent with the wrestling match interpretation. ("Recall" is in quotation marks here because the subjects' protocols contained a great many inferences that, not surprisingly, were not present in the original passages.)

Several other studies have shown that expertise, or the lack of it, can affect the amount of recall as well as the type. Chiesi et al. found that individuals with a high level of baseball knowledge recalled significantly more gist units from both normally ordered and scrambled baseball sequences than low-knowledge individuals did, although the opposite pattern of performance was true with regard to verbal descriptions unrelated to baseball. Chiesi et al. also found that the effects of expertise were only present when information about baseball was placed in an appropriate context. Target sentences placed in a paragraph concerning a baseball sequence were more likely to be recalled by high-knowledge than low-knowledge individuals, whereas target sentences presented in isolation were recalled equally well by both groups.

In a now-classic study of adult experts and novices in chess, Chase and Simon (1983) found that, after being shown chess boards with the pieces in various locations, experts could recall up to three times as many locations of particular pieces as novices could. And in a similar experiment involving the clever twist of child experts and adult novices in chess, Chi (1978) found that, in spite of evidence from previous studies (e.g., Case, 1974) suggesting that the short-term-memory capacity of children is smaller than that of adults, the child experts still recalled significantly more locations than the adult novices. (The implications of Chi's findings will be discussed more fully in the section on developmental theory.)

Although there is little available research examining the ways in which domain-related information is subsequently utilized, one experiment in the Chiesi et al. study suggests that experts and novices may

differ in this respect as well. Chiesi et al. found that when their subjects had finished reading descriptions of baseball plays and were asked to produce statements that would continue the various plays, high-knowledge individuals were not only able to produce a greater number of continuation statements but were also able to produce more important ones (i.e., statements that were more significant in terms of the goal structure of baseball). These results are important because they indicate that having expert knowledge in a domain may not only aid in the retention of new domain-related information, but may also increase the number and quality of available options for acting upon that material.

Finally, having examined some of the ways in which expertise appears to positively affect the recognition, recall, and subsequent utilization of information, it is of interest to consider the way in which expert and nonexpert knowledge is represented in memory. Chi and Koeske (1983) have approached this question by investigating a single subject's representation of more and less well-known subsets of knowledge in a single topic area. The subject of the study is a 4½-year-old boy, and the topic area under consideration is knowledge of the names and characteristics of various types of dinosaurs.

Essentially, Chi and Koeske found that the child's representation in memory (as determined by sequential recall tasks and the child's ability to identify dinosaurs according to their properties) of 20 well-known and 20 less well-known dinosaurs was different in three ways. First of all, the well-known set of dinosaurs contained a greater number of links between individual dinosaurs than did the lesser-known set. This means that the name of any well-known dinosaur was triggered in memory by a greater number of different types of dinosaurs than was the name of any lesser-known dinosaur. Second, the memory links between the well-known dinosaurs were stronger than those among the lesser-known dinosaurs, which means that the number of times that the name of one particular dinosaur triggered the name of another particular dinosaur was greater among the well-known set than among the lesser-known set. Third, a greater amount of internal cohesion was present in the memory representation of the well-known set than in the lesser-known set. This means that, in the well-known group, dinosaurs that shared similar properties were more likely to be mentioned together, whereas in the lesser-known group, this grouping according to properties was not found. Taken as whole, Chi and Koeske's results indicate that the representation of knowledge in an area of expertise is richer, and more strongly and consistently interrelated, than is the representation of nonexpert knowledge, which implies that an expert's knowledge is not only greater than that of a nonexpert but is organized differently as well.

Research on Strategic Learning

Up to this point, the discussion has focused on the possession of factual knowledge and its beneficial effects on the acquisition of knowledge in the same domain. But what about active or strategic

knowledge? Does its possession also lead to an increased ability to learn? And does the process of strategic learning provide any evidence for the argument that learning is domain-specific? The following discussion is designed to provide some insight into these questions.

Beginning primarily with the work of Flavell (e.g., Flavell, 1970; Flavell, Beach, & Chinsky, 1966), the study of cognitive strategies has been the subject of a great deal of developmental research within the past two decades. Although several basic types of strategies have been investigated, such as rehearsal (Flavell et al., 1966; Ornstein & Naus, 1978), categorization (Moely, 1977), elaboration (Rohwer, 1973), and retrieval mechanisms (Kobasigawa, 1974), by far the greatest amount of attention has been devoted to the strategic use of rehearsal (Brown et al., in press). In general, the research concerning these strategies indicates that, although adults spontaneously use them when engaged in learning, children do not (Kail & Hagen, 1977).

Along similar lines, the studies of scientific reasoning by Piaget (1926; 1929; 1954; 1970a; 1970b) and others (e.g., Braine, 1968; Brainerd, 1973; Shantz & Smock, 1968) have concluded that children and adults bring different abilities to the problem-solving process, and hence children are unable to engage in many of the success-inducing strategies that are routinely generated by adults.

In both of these areas, attempts have been made to train children to use the strategies in question and have met with variable amounts of success. Although an adequate review of the training literature is well beyond the scope of this paper, a general finding is that these training studies have not been able to induce transfer to novel but applicable situations (see Belmont & Butterfield, 1977, and Denney, 1973, for results of training studies in information processing; see Kuhn, 1974, for results of Piagetian training studies).

The importance of these findings for the present paper hinges on this issue of nongeneralizability. If the strategies for successful memorization or problem-solving in a particular domain can be taught to children, but children fail to apply them to other relevant domains, then perhaps domain-specificity is a characteristic of procedural knowledge as well as of factual knowledge.

Although there are fewer studies concerned with teaching strategic knowledge to adults than to children, there is at least some evidence to suggest that this problem of transferability may apply to them as well. In a study of analogical problem solving (i.e., solving a problem by the use of analogy), Gick and Holyoak (1980) have found that adults will transfer an appropriate solution from one applicable situation to another when they are provided with a hint to do so, but that transfer frequency drops markedly when only spontaneous generalization is considered.

In addition to the problem of nongeneralizability in many strategy-training studies, there is also evidence from research on task variables indicating that the effectiveness of strategic knowledge is at least partially dependent upon the context in which it is used. For

example, Perlmutter and Myers (1979) have shown that the strategies employed in recognition memory appear to be the same for preschool and school-aged children when the items used in the memory task are distinct and familiar to the children. Age differences in performance appear, however, when either complex stimuli or stimuli that are more familiar to one age group than another are used. Gelman and others (Gelman, 1978; Gelman & Gallistel, 1978) have made a similar point involving the use of familiar and unfamiliar materials and settings in Piagetian tasks. And Ornstein and Naus (1978) have demonstrated a relationship between the strategic use of rehearsal and both the nature of the material to be learned and its potential for being organized.

Summary

In this section, evidence has been drawn from three areas of research to demonstrate that previously acquired knowledge affects the learning of subsequent, related information. From the research on prior knowledge, we have seen that the level of prior experience within a domain is directly related to the degree of information recognized and recalled from prose passages concerning that domain. In the case of an ambiguous passage, even a slight amount of meaningful prior information can substantially improve memory for the passage, presumably because the prior information allows a schema to be invoked, which in turn allows a deeper understanding of the material to occur. When prior information about a passage causes a conflicting schema to be instantiated, memorability significantly decreases. And when various types of prior information provide equally meaningful frameworks for the same passage or problem-solving situation, the type of information that is recalled or the particular solution that is chosen will depend on the particular prior information that was received. Finally, it is of particular interest to note that the effects of prior information appear to be relatively age-independent. Young children, adolescents, and adults seem to benefit equally well from access to prior information about a passage in that their recall protocols demonstrate similar patterns of recognition, recall, and intrusion.

From the related research on experts, we have seen that having expertise in an area affects subsequent learning in much the same way as the possession of more modest types of prior knowledge: the degree of recognition and recall are increased, and the type of information recalled is dependent upon one's perspective as an expert or novice in the domain under consideration. In addition, it appears that concepts in an area of expertise are represented in memory in a richer and more interrelated manner than less well-known concepts, which perhaps partially accounts for the expert's greater efficiency in learning. And, once again, it appears that children may benefit from expertise in much the same way as adults, although no research has been reported which systematically examines this area.

In the area of strategic knowledge we have seen evidence for the effects of knowledge on subsequent learning in two areas: the effects of item familiarity on the use of strategies, and the failure of strategic training techniques to elicit transfer to other problem

domains. Since most of this research has been conducted with children, it is difficult to determine exactly how the influence of knowledge on strategic learning changes with age. There is at least some indication, however, that the patterns for children and adults may be similar.

Overall, then, the research from these three areas allows two preliminary conclusions: 1) prior knowledge does indeed have an effect on subsequent learning, and 2) children and adults seem to benefit from prior knowledge in similar ways. Although the evidence for both of these conclusions is more compelling in the case of factual knowledge than in the case of strategic knowledge, the evidence at least suggests that strategic learning is not completely content-independent.

Evidence for Domain-Independent Learning

Given the persuasive body of evidence in the last section, it is unlikely that any researcher in the area of cognitive psychology could hope to develop a totally content-free theory of learning. There are, however, greater and lesser degrees of context dependence, and the present section is devoted to examining the possibility that at least some levels of learning are relatively domain-independent.

Research on Metacognitive Training

The fact that many of the attempts to train strategic knowledge in children failed to elicit transfer, as noted in the previous section, has caused some researchers to examine the area of strategic knowledge more carefully. As Belmont and Butterfield (1977) noted:

> Having documented the children's deficient programs and the adults' efficient ones, what does the researcher not know? He does not know how adults program themselves, nor what is lacking in the children's programming that prevents their arriving at mature strategies. The processes involved in strategy invention are what Flavell . . . (1970) and others have called the "executive" functions of cognition. These functions are the means by which people manage simultaneously to be programmers and processors. (p. 461)

Clearly, Belmont and Butterfield believe that if these types of executive functions could be taught to children then the gap in strategic knowledge between children and adults would decrease or even disappear. And implied in this belief is the presumption that the transfer failures that were characteristic of earlier training studies would disappear as well.

Although too few metacognitive training studies have been conducted to allow definitive conclusions to be reached, a study by Brown, Campione, and Barclay (1979) suggests that this presumption may be true. Brown et al. taught a group of 11-year-old retarded children how to use memory strategies as well as how to monitor their own learning via self-testing. The students in this experimental group significantly improved their pretraining performance, outperformed control group students, and continued to exhibit superior performance for at least a year after the training session. Most importantly, however, they were able to transfer their successful use of recall strategies from the lists of unrelated pictures used in training to short prose passages.

Although Brown et al.'s results are encouraging, they should not be taken as an indication that metacognitive skills are completely domain-independent. Once again there are too few studies to allow for definite conclusions, but a recent study by Stein and Trabasso (1980) suggests that the domain of information is as important a consideration in metacognitive studies as it is in other types of studies. Stein and Trabasso, bothered by Markman's (1979) finding that even sixth-grade children have difficulty recognizing inconsistent information in prose

passages, designed a comprehension monitoring study to determine whether young children could detect inconsistencies in a more meaningful situation (Markman's passages had contained unfamiliar information). Kindergarteners and third graders heard stories in which the protagonists' actions were either congruent or incongruent with their personality traits. For example, in one congruent story a boy who was always kind helped a girl who fell down in the street. In the corresponding incongruent story, he kicked her in the face. When children were asked if these stories made sense, both kindergartners and third graders said no to significantly more incongruent than congruent stories, suggesting that even preschoolers can detect inconsistent information in prose passages when the context is a meaningful one for them.

Research on Adult Strategic Learning

So far, the best evidence that has been provided for the argument of relatively domain-independent learning is Brown et al.'s finding that metacognitive strategy training in children can elicit transfer to a new domain. An interesting study of adult learning by Anzai and Simon (1979) makes another important contribution to this argument.

Anzai and Simon observed a single adult subject solving a complex task (working through the Tower of Hanoi problem three times) as she talked aloud about the strategies she was using. They analyzed the thought processes she had engaged in as she learned to solve the task increasingly more efficiently and attempted to deduce the subprocesses involved in her reasoning. Then they designed a computer program that incorporated the hypothesized subprocesses and were able to mimic the subject's progression toward more and more efficient task solution. By comparing this production system to the subject's own protocol, Anzai and Simon concluded that the subject used at least three different types of information to learn new strategies in the context of older ones. The three types of information were (1) task-dependent information that was obtained from the task instructions, (2) task-dependent information that was obtained from observing the course of the solution, and (3) task-independent prior information about classes of possible strategies. The classes of possible strategies were the avoidance of repetitious moves, means-end analysis, and the condensation of a sequence of moves into a single chunk.

From Anzai and Simon's thought-provoking analysis the possibility emerges, as it does from Brown et al.'s study, that the use of certain high-level strategies may be independent of the subject domain, even though their implementation requires prior information about both the domain and lower-level strategies.

A Current Theory of Knowledge Acquisition

This thesis is essentially the same as that recently proposed by Sternberg (1983) in a theory concerning the development of cognitive competence. While acknowledging the importance of domain-specific processes, Sternberg argued that domain-independent processes must also

play a role in learning, since mere exposure to an extensive knowledge base is not sufficient for developing expertise in an area.

Sternberg's theory specifies three major categories. The first of these categories concerns the types of informational cues that learners must be aware of in order to acquire knowledge. These cues consist of the timing of an event (or concept or procedure), its location, value, properties, purposes, causes, equivalences, and the classes to which it belongs. For example, when acquiring a new vocabulary item, the learner must be sensitive to where the word occurs in a sentence, what its properties and purposes appear to be, what equivalences it might have, and so on. The second category of Sternberg's theory specifies the types of processes that learners must engage in to make sense of the available cues in a given situation. These processes consist of (1) selective encoding, or determining which information is relevant and which is irrelevant; (2) selective combination, or putting together relevant information to make sense of its underlying pattern; and (3) selective comparison, or choosing from previously acquired information to provide relationships to new information. The third category of Sternberg's theory specifies different variables that affect the manner in which the above processes act upon the above cues. These moderating variables consist of the number of times a new item occurs, the number and types of contexts in which the item occurs, the location of cues about the item in relation to the item itself, the degree of importance attributed to the item, and the density of items to be learned.

Sternberg's theory is interesting because not only does it seem consistent with the findings of both Brown et al. and Anzai and Simon, but it also provides a rich basis for developing further research questions in this area. Thus, it provides another step toward demonstrating that some aspects of learning may be domain-independent.

Summary and Discussion

In this section we have seen some modest but convincing evidence for the argument that at least some aspects of learning may be relatively domain-independent. This evidence has consisted of a demonstration that training children to use metacognitive skills enables the transfer of these skills from one domain to another and development of a computer program that can mimic adult learning when it is provided with task-independent as well as task-dependent information. In addition, a theory has been presented that allows for both domain-specific and domain-independent components in learning.

When the evidence from this section and the previous section is examined together, a somewhat cohesive picture begins to take form. First of all, the domain in which learning occurs and the amount of expertise the learner has in that domain are factors that appear to affect both factual and strategic learning at all levels and to affect adults as well as children. Second, this effect seems to be the strongest in the case of factual learning and to apply to adults, adolescents, and children to the same degree. Third, although this effect also occurs in the area of basic strategic learning, it is

probably considerably diluted. It may also apply similarly to children and adults, but, since most of the developmental studies concern strategies with which adults are already proficient, it is difficult to say. Finally, it appears that this effect of domain on learning is the weakest of all in the area of metacognitive strategic learning, for both children and adults, and may even approach some infinitesimally small magnitude with adults who already have an arsenal of strategies at their command.

Implications for Developmental Theory

Although the question of how dependent learning is upon content area knowledge is a perfectly fascinating question in its own right, it is of special importance to developmental psychologists because it strikes at the very heart of another question, namely, exactly what constitutes cognitive development. This section is an attempt to deal with this question in light of the research examined in the last two sections.

Prevailing Theories

In general, development is often conceived of as a movement from the specific and context-bound toward the general and context-free, with conflict of some form acting as the change-inducing mechanism. But the specific loci of movement and conflict have been hotly debated for decades. Some of the more popular contenders are briefly examined in the following paragraphs.

In the American behaviorist tradition (e.g., Skinner, 1938), development has been perceived as a change in the individual's behavior resulting from feedback from the environment. This theory essentially views the individual as a passive recipient of, and responder to, information from the environment and as a result does not consider any impact that the individual him or herself may have on the environment. Learning occurs gradually, and in a quantitative fashion, as the individual receives increasingly greater amounts of environmental information.

In the European organismic tradition (e.g., Inhelder & Piaget, 1958), development is seen as a change in the individual's understanding of the world, which results from an interaction between the biological maturation of the individual and its environment. In this theory the individual is seen as an active participant in its development, simultaneously altering the environment to meet its own needs and adapting to it. Development occurs in qualitative jumps, or stages, as the individual matures and acts on the world from a new biological viewpoint. In this theory, learning is limited, in quality, by the particular vantage point that the individual possesses at the time.

In more recent years, some of the neo-Piagetians (e.g., Case, 1972; Pascual-Leone, 1970) have turned, once again, toward a more quantitative emphasis for explaining developmental change. In this theoretical framework, much of Piaget's theory remains intact with a notable exception: development is viewed as the result of the individual's increase in capacity, or processing space, as biological maturation occurs. The quality of an individual's understanding of the environment has a ceiling on it which is imposed by the quantity of processing space available to the individual at any particular time. Learning consists of the conceptual reorganization that occurs as capacity increases allow more and more factors to be maintained, simultaneously, in memory.

After the brief sketches of these three theories, it is of interest to see how well each of them can account for the findings reviewed in the preceding two sections. It has been repeatedly demonstrated that behaviorism's failure to recognize the active nature of the individual, and its corresponding effect on the environment, makes it a poor candidate for explaining developmental change. For example, in the area of language development alone there are many examples (see de Villiers & de Villiers, 1978) of behaviors that cannot be explained by a stimulus-response model, such as children's overgeneralizations and other rule-governed errors that do not occur naturally in the environment. Along similar lines, learning theory has great difficulty dealing with the notion of "schemata," discussed in the first section of this paper. Although the theory may be able to account for the development of a schema (i.e., the observation of multiple examples of a category in the environment), it cannot explain the way in which individuals' already formed schemata have been shown to significantly influence their subsequent course of learning.

With Piaget's organismic theory of development, such concepts as "schemata" can be easily explained in terms of the individual's alternating and simultaneous pattern of accommodating and assimilating information in the environment. Piagetian theory, however, has difficulty explaining the effect that prior knowledge has on the acquisition of concepts. Research has shown (Brainerd, 1978) that children are not only more likely to display evidence of a concept, such as the ability to conserve, when they are tested in a familiar medium, but in addition they are more likely to display differences in the acquisition of various instances of the same concept, such as the conservation of volume and the conservation of mass. And these differences in acquisition can be accounted for by differences in their prior knowledge of the two domains. Although Piaget recognizes these phenomena and referred to the latter as horizontal decalage, his theory of domain-independent structures cannot adequately account for them. In fact, they undercut the very foundation of the groupements.

Finally, we turn to the theory of capacity growth as an explanation for developmental change. As described above, this theory accounts for the differences between children's and adults' performance on tasks by postulating that memory capacity increases with age. Although there is much research to support this apparent discrepancy between children's and adults' memory spans (Case, Kurland & Goldberg, in press; Huttenlocher & Burke, 1976), a study conducted by Chi (1978), discussed in the first section of this paper, provides data that are difficult for the theory to reconcile. Chi found that child chess experts could remember significantly more positions on a chess board than adult novices in chess could remember, which would be a highly unlikely finding if children do, indeed, have a smaller memory capacity than adults.

An Alternative Theory

If the prominent developmental theories discussed above have difficulty in accounting for the growing evidence that knowledge in a domain significantly alters subsequent learning in that domain, then what type of available theoretical framework is capable of accommodating this research? One candidate that has been increasing in popularity recently (e.g., Brown et al., in press; Chi & Rees, 1983) is a knowledge-based developmental theory that contains two postulates. The first of these is that development occurs as the direct result of an increase in, and the consequent restructuring of, procedural and factual knowledge (Chi & Rees, 1983). Lest this statement be interpreted as indicating that all growth is quantitative in nature and naively ignoring the mountains of research that demonstrate the qualitative nature of development, Chi and Rees hasten to explain that "simply adding to any structure can make it more powerful and produce an apparent qualitative change. Thus, while the qualitative-quantitative distinction is useful for our purpose of highlighting developmental explanations, it should not be taken too literally" (p. 21). Some of the ways in which the theory deals with child-adult differences in task solution is to point to "quantitative" differences in procedural knowledge that could account for "qualitative" differences in task performance, such as chunking (Chi, 1976), the development of larger semantic networks (Chi & Koeske, 1983), and the use of more complicated rule strategies (Siegler, 1983).

The second postulate of this knowledge-based theory, which follows directly from the first, is that children and adults basically think and learn in the same way (Carey, in press). Not only does this postulate appear to be supported by the research on prior knowledge reviewed in the preceding sections of this paper, but evidence from other areas is accumulating as well. Some examples of this evidence, observed in language acquisition and problem-solving, are summarized below.

In the area of language acquisition, one of the older observations of child-adult similarities in processing was made by Stolz and Tiffany (1972). Stolz and Tiffany were interested in the finding that groups of young children could reach little agreement in their responses to word association tasks, in contrast to the pattern of tight agreement found among groups of adults. Hypothesizing that the difference in patterns was due to children's relative lack of vocabulary knowledge, Stolz and Tiffany retested adults using relatively unfamiliar stimuli. Under these conditions, the adults' association patterns were similar to those observed in children in the earlier study.

In a more recent investigation, Bowerman (1982) observed U-shaped language acquisition curves among young children, curves that demonstrate a period of mastery, then a drop in mastery, followed by a final period of mastery. She has observed children go through a period of substituting verbs such as put and take for make, and of using spatial words to infer meaning in an abstract domain, such as time. Bowerman hypothesized that these errors are the result of children's growing understanding of the abstract semantic relationships that exist among words in superficially different semantic domains. They appear to

be very similar to the types of "slips of the tongue" that are made by adults (e.g., Fromkin, 1973; Nooteboom, 1969).

In the area of problem-solving, interesting examples of child-adult similarities have been observed, as well. One of these similarities relates to isomorphic problems, those that have an identical logical structure but vary in their surface form. As in the case of D'Andrade's study, described in section one (i.e. the Sears' store managers versus the quality control experts), adults often experience more difficulty in solving one of the surface forms of an isomorphic problem than they do in solving the others (Newell & Simon, 1972). As Chi and Rees pointed out, this is precisely what has been observed in preoperational children who exhibit horizontal decalage when solving different forms of a Piagetian conservation task.

Perhaps the most interesting example of problem-solving similarities among different age groups has been provided by Karmiloff-Smith and Inhelder (1974/75), however. They conducted a microgenetic study of children, ranging from 18 months to nine years in age, who were engaged in solving a balance beam problem. Karmiloff-Smith and Inhelder observed that, at the very earliest ages examined (18-39 months), children concentrated on exploring the materials themselves, rather than balancing the blocks. At ages four to six, children appeared to be mainly goal-oriented and balanced each block individually. Then, gradually, a theory of the geometric center evolved, which guided the goal-oriented behavior. As actions became successively theory-oriented, however, blocks that did not follow theoretical predictions (i.e., blocks that were heavier on one end than the other) were rejected as "unbalanceable," even though they previously had been balanced by the children. As children became more and more aware of counterexamples to their geometric center theory, they evolved a separate theory, involving weight, which was used to account for the counterexamples only. Eventually, by age nine or so, children were able to combine their separate theories into a single, comprehensive theory.

Although the sequence described above sounds like a typical developmental one, the interesting observation made by Karmiloff-Smith and Inhelder was that individual children exhibited, over their period of experience with the problem, many of the different types of behavior, rather than just one. So, for example, an older child might be observed exploring the blocks, then following a goal-oriented strategy, and later developing the geometric center theory, all in the same half-hour session. In addition, Karmiloff-Smith and Inhelder noted that the same order of strategies that was observed across subjects was also observed within subjects, regardless of where in the sequence a child started. Equally interesting is Brown et al.'s (in press) observation that Anzai and Simon's (1979) adult subject passed through a similar sequence of stages when she first learned to solve the Tower of Hanoi problem: a goal-oriented stage, a theory-in-action stage, and finally a reflective stage characterized by thought before action.

Summary

In this section, three prominent developmental theories (learning theory, Piagetian theory, and the "capacity" theory of information processing) have been examined with respect to the research findings concerning prior knowledge that were summarized in the previous sections. For various reasons, each of these theories has difficulty in accounting for some aspect of the findings.

Accordingly, a knowledge-based theory was presented that can adequately account for these data. This theory explains development in terms of the amount of factual and strategic knowledge that an individual has acquired about the world and argues that it is the unequal distribution of this knowledge that accounts for the apparent differences in children's and adults' reasoning processes. Additional evidence, from the areas of language-acquisition and problem-solving, was provided to support this theory.

Conclusions

Having examined a good portion of the data dealing with the relationship between knowledge and its effect on learning, and having discussed the adequacy of major developmental theories in accounting for this relationship, we will step back from the picture and consider what types of questions have gone unanswered and what directions for future research might be most fruitful.

First of all, although the research on learning and knowledge that is reviewed in this paper appears to be unexplainable in terms of the prominent developmental theories, neither the research nor the theories should be automatically dismissed. Careful consideration of the methodology of past, present, and future studies must be undertaken to ensure that current interpretations accurately represent reality. And only the aspects of theories that conflict with methodologically sound discoveries should be altered, to avoid throwing away any valid constructions in the process.

Perhaps the biggest problem confronting the body of research reviewed is the lack of sound developmental comparisons, and this criticism applies to nearly every area covered in the present paper. Too few studies have concomitantly examined both children and adults using the same (or equivalent) materials, directions, and so on. The lack of good developmental data is especially acute for both the research concerning procedural knowledge and that concerning the similarities in thought between children and adults.

Of course, the methodological problems involved in studies of this nature would be considerable, since adults and children of various ages have widely differing amounts of factual and procedural knowledge in nearly every area imaginable. Perhaps some of the methodological problems could be circumvented, however, by using material that is equally unfamiliar to both children and adults, or by choosing separate subject matter that is appropriate for each individual age group and trying in some way to equate for the levels of meaningfulness and familiarity. A particularly fruitful approach to the question of child-adult similarities appears to be the construction of situations that result in child-like thought patterns among adults. This approach can help us to ascertain where children are beginning, which is just as important as where they will arrive, as Belmont and Butterfield (1977) have pointed out. Regardless of which methods are chosen, some attempts to overcome these problems must be made before developmental questions can be answered with any degree of confidence.

A second problematic area is the lack of any data at all concerning some age groups. The populations that have been studied most frequently are the ones most available to researchers, namely elementary school students and undergraduates. In all areas, research concerning infants, preschoolers, adolescents, and older adults is essential. Research aimed at finding similarities between child and adult patterns of thought, in particular, must carefully examine a greater number of age groups and specifically must deal with the question of how physical

maturation affects the strategic thought of infants and very young children.

Another question which remains unanswered, largely because it has gone unasked, is the question of individual differences. From a developmental standpoint, it is important to consider the types of differences that occur within an age group, in comparison to those that may or may not exist between age groups. Research on individual differences in the area of experts would be particularly meaningful (and particularly interesting!), since large differences have been found in this area. Research in this vein would be especially interesting for answering questions such as, How does one become an expert in an area? Is frequent exposure to a large and well-organized data base sufficient? How does expertise change with age? Are the differences between experts' and novices' representation and processing of information largely quantitative, qualitative, or both? And is it possible to become "unexpert" in a former area of expertise; in other words, can one "turn off" the expert processing of information, or does it become automatic?

Finally, it is important to ponder a philosophical question that emerges from this review. If the knowledge-based theory of development described in the last section is, indeed, accurate, how does that affect our conceptualization of what "development" really means? And how will it affect the types of developmental questions that are asked? One immediate possibility is that a shift in focus may occur from the individual to the environment. In this case, a good deal of research effort would probably be directed toward training studies and educational technology. Another possibility is that the emphasis may still be on individuals but would shift from questions concerning group and age differences to those concerning individual differences, as discussed above. Another possibility is that more research would focus on the roles that heredity and physiology play in learning and development, especially concerning infancy and aging. Regardless of which, if any, of these speculations comes to pass, however, the growing accumulation of research on the interaction between knowledge and learning indicates that developmentalists are tackling this issue head on.

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Appendix

Ambiguous passages from Anderson, Reynolds, Schallert, and Goetz, 1976

I

Rocky slowly got up from the mat, planning his escape. He hesitated a moment and thought. Things were not going well. What bothered him most was being held, especially since the charge against him had been weak. He considered his present situation. The lock that held him was strong but he thought he could break it. He knew, however, that his timing would have to be perfect. Rocky was aware that it was because of his early roughness that he had been penalized so severely--much too severely from his point of view. The situation was becoming frustrating; the pressure had been grinding on him for too long. He was being ridden unmercifully. Rocky was getting angry now. He felt he was ready to make his move. He knew that his success or failure would depend on what he did in the next few seconds.

II

Every Saturday night, four good friends get together. When Jerry, Mike, and Pat arrived, Karen was sitting in her living room writing some notes. She quickly gathered the cards and stood up to greet her friends at the door. They followed her into the living room but as usual they couldn't agree on exactly what to play. Jerry eventually took a stand and set things up. Finally, they began to play. Karen's recorder filled the room with soft and pleasant music. Early in the evening, Mike noticed Pat's hand and the many diamonds. As the night progressed the tempo of play increased. Finally, a lull in the activities occurred. Taking advantage of this, Jerry pondered the arrangement in front of him. Mike interrupted Jerry's reverie and said, "Let's hear the score." They listened carefully and commented on their performance. When the comments were all heard, exhausted but happy, Karen's friends went home.

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